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Modeling cyclist acceleration process for bicycle traffic simulation using naturalistic data

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ABSTRACT

Cycling is a healthy and sustainable form of transportation. The recent increase of daily cyclists in Sweden has triggered broad interest in finding how policies and measures may facilitate the planning of bicycle traffic in the urban area. However, in comparison to car traffic, bicycle traffic is still far from well understood. This study is part of the research effort to investigate microscopic cyclist behavior, model bicycle traffic and finally build a simulation tool for applications in transport planning. In particular, the paper focuses on representing bicycle movements when the cyclist doesn't interact with others. The cyclist acceleration behavior is modeled using naturalistic GPS data collected by eleven recruited commuter cyclists. After filtering the large amount of data, cyclist trajectories are obtained and acceleration profiles are abstracted. A mathematical model is proposed based on the dataset, and three model forms are estimated using the maximum likelihood method with Laplace and Normal error terms. While the model with more parameters shows superior performance, the simplified ones are still capable of capturing the trends in the acceleration profiles. On the other hand, the study also introduces social economic characteristics of cyclists to explain the model parameters and they show significant effects. However, the cyclist population being investigated in the study is still limited, and more convincing results can be obtained when the data collection effort is extended to larger population with more variable cyclist characteristics.

1. Introduction

Many cities in Europe and US have witnessed the growing cyclist population over the past decades. Although the size of this community is still small in comparison to motorized vehicles, increasing attention has been given to its high level of vulnerability in traffic safety research. In the meanwhile, a tremendous demand for more knowledge of the characteristics specific to this traveler group has also been identified provided the new policy trend for sustainable transport development. As the popularity of cycling increases at a fast pace in most urban areas, both traffic planners and policy makers have also been seeking useful analytical tools which can effectively facilitate addressing bicycle-related planning and operational issues. Since the development of these tools, such as bicycle traffic simulation models, highly depends on sufficient understanding of cyclist behavior, it becomes even more urgent for researchers to initiate related studies.

In comparison to the overwhelming research effort on car traffic, the study on bicycle traffic is still far behind. However, both car and bicycle traffic flows show complex patterns due to their frequent interactions within the traffic system.

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In particular, the behavior of cyclist and driver plays a central role. Therefore, in order to improve the planning practice of bicycle traffic, it is important to understand how cycle traffic is represented by individuals, how cyclists manipulate their speed levels and interact with each other, and moreover how they interact with cars.

1.1. Relevant studies

As an effective and efficient tool, traffic microscopic simulation models are extensively used to appraise proposed transport policies and measures before they are implemented. Nevertheless, the accuracy and reliability of these appraisals are greatly dependent on the understanding of the road users' behavior, as well as modeling of their movements and interactions among one another. While the significance of bicycle as a convenient and environmentally friendly non-motorized transport modes has been highlighted by many researchers, there is still a considerable gap in the current literature in comparison to more fruitful results of driver behavior and vehicle traffic flow. Twaddle, Schendzielorz, and Fakler (2014) suggested several facts making bicycle traffic quite different from vehicle traffic, i.e. the dynamic characteristics of cyclists, including their speed, acceleration and deceleration profiles, and the physical characteristics, including size, flexibility and capability.

Experiences from research on motorized vehicles indicate that the availability of sufficient field data, or naturalistic data is extremely important to the understanding and modeling of cyclist behavior. Given the demand of high quality data, the Instrumented Probe Bicycle (IPB) became an attractive and reliable tool. Although currently there is no standardization of IPB, this technology is developing at a fast pace and many researchers have attempted to carry out bicycle-related studies using data collected by various IPBs. Early on the IPB was quite basic with a few types of equipment mounted and most of those studies merely aimed at investigating the cyclist behavior on a relatively macroscopic level, such as identifying the risk factors existed in the bicycle activities (e.g. Walker, 2007; Johnson, Charlton, Oxley, & Newstead, 2010) and obtaining cycling routes and speed distributions (e.g. Parkin & Rotheram, 2010; Addison & Low, 1998). Most recently, however, more developed IPBs emerged and deeper insights into bicycle mobility have also been presented. For instance, Joo and Oh (2013) employed an IPB equipped with a set of sensors including a GPS receiver, accelerometer, and gyro sensor. According to their report, useful data for identifying longitudinal, lateral, and vertical maneuvers in bicycle movement could be obtained from the IPB. Owing to the abundant data, an intelligent system called Bicycle Monitoring Index (BMI) which can be used to evaluate the safety and mobility of the bicycle environment was developed using the fault tree analysis (FTA) technique. Later, Dozza and Fernandez (2014) applied an advanced IPB with multiple sensors to study bicycle dynamics and cyclist behavior. Longitudinal, lateral, and vertical accelerations were measured and further processed by a specialized software. The main conclusion was that high quality naturalistic data from the IPB laid a solid foundation for further development of bicycle-related applications.

In comparison to the overwhelming research effort on driver behavior and vehicle traffic simulation, the modeling of cyclist behavior and bicycle traffic is still a relatively undeveloped area. Early attempts were made (e.g. Ferrara & Lam, 1979) to study cyclists' crossing behavior at intersections using computer simulation. In Europe where cycling has always been more prevailing than in the U.S, research on bicycle traffic and operation turns out to be more thriving. For example, researchers in the Netherlands developed a simulation tool to examine the level of service of separate bicycle facilities with mopeds included (Botma & Papendrecht, 1991, 1993; Botma, 1995). In Finland, Kosonen (1999) developed a simulation program mainly for vehicle traffic but bicycle mode was included based on the same car-following logic. Taylor and Davis (1999) reviewed many studies on bicycle transport and pointed out that limited computer simulation program was available by that time. Faghri and Egyháziová (1999) then identified the requirement of mixed simulation models involving motor vehicles and bicycle traffic. They thereof proposed a microscopic simulation model BICSIM. A simple biking following logic based on the total safety distance model was developed and implemented in the simulation tool.

Most recently, several microscopic traffic simulation tools, widely used in road traffic modeling and analysis, have been extended with the bicycle mode to meet the requirements for scientific and commercial applications. VISSIM, AIMSUN and SUMO are typical examples of such tools. Twaddle et al. (2014) did a comprehensive review of the latest work on bicycle and mixed traffic modeling. In particular, they summarized the modeling approaches for bicycle movement into four categories: longitudinally continuous models, cellular automata models, social force models and logic models. The majority of current microscopic traffic simulation tools model the longitudinal and lateral motion of road users separately (e.g. car-following and lane changing models are often applied for vehicle traffic). Therefore, the same approach can be naturally extended for modeling cyclist behavior. Moreover, Oketch (2000) proposed an approach for modeling mixed-traffic streams which allows the inclusion of different kinds of transportation modes, such as motorcycles, bicycles, and three-wheeled vehicles.

Cellular automata (CA) are discrete models not only on time but also on space (Nagel & Schreckenberg, 1992). The approach has been extensively applied to represent vehicle traffic from microscopic to more aggregate models (Gould & Karner, 2009). In order to describe bicycle movement, cyclists can also be assumed to move across the discrete cells of bicycle path based on the rules established. The approach provides an effective way to investigate the interactions between road users. For instance, Zhao et al. (2013) attempted to model passing events in mixed bicycle traffic with CA.

The social force model has been originally used in pedestrian dynamics. The concept has been further extended for modeling bicycle's move in reaction to a number of attractive and repulsive forces. Movement within social force models is not bounded to the longitudinal and lateral directions. So the approach is usually computationally more expensive. Meanwhile, attempt has been made to represent the behavior of and interaction among cars, pedestrians and bicycles by a social force model (Schönauer, Stubenschrott, Huang, Rudloff, & Fellendorf, 2012). Logic models tend to include the detailed tactical